Analysis and High-Resolution Modeling of Tropical Cyclogenesis during the TCS-08 and TPARC Field Campaign

PI: Tim Li
IPRC/SOEST, University of Hawaii at Manoa
1680 East-West Road, POST Building 409B
Honolulu, Hawaii 96822
Phone: (808) 956-9427 fax: (808) 956-9425 e-mail: timli@hawaii.edu

Co-PI: Melinda S. Peng
Naval Research Laboratory
Monterey CA 93943-5502
Phone: (831) 656-4704 fax: (831) 656-4769 e-mail: melinda.peng@nrlmry.navy.mil

Award Number: N000140810256

LONG-TERM GOALS

The long-term goal of this project is to improve the prediction of tropical cyclone (TC) genesis, structure and intensity changes through improved understanding of the fundamental mechanisms involved. The accurate prediction of TC genesis, structure and intensity changes is critical to Navy missions and civilian activities in coastal areas. Significant gains have been made in the TC track prediction over the past decades. The genesis and intensity forecast, however, has shown very little progress during the same period. A main factor contributing to the lack of skill in the prediction of TC genesis and intensity is the lack of observations prior to and during TC genesis and intensification periods and the inadequate understanding of physical mechanisms that control the cyclogenesis and intensity change. The TCS-08 and TPARC field campaign provide an unprecedented opportunity for us to gain the first-hand insight of observed characteristics of TC genesis in western Pacific and to compare them with high-resolution model simulations. By analyzing and assimilating these data, we intend to understand the physical mechanisms that involve the TC internal dynamic and thermodynamic processes, external forcing, and scale interactions. Only after thoroughly understanding these processes, can one be able to tackle the weaknesses in the current state-of-art weather forecast models.

OBJECTIVES

The objective of this project is to investigate the synoptic and climatic aspects of tropical cyclone (TC) genesis in the western North Pacific (WNP). On one hand, specific synoptic and dynamic processes through which an initial weak vortex (either mid-level or near-bottom vortex) develops into a TC will be investigated in a cloud-resolving model. On the other hand, the large-scale control of the Madden-Julian Oscillation (MJO) and El Nino-Southern Oscillation (ENSO) on TC genesis in the WNP will be examined. Additional effort is to conduct data assimilation using data collected from TCS-08

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2011**	2. REPORT TYPE	3. DATES COVERED **00-00-2011 to 00-00-2011**

4. TITLE AND SUBTITLE **Analysis and High-Resolution Modeling of Tropical Cyclogenesis during the TCS-08 and TPARC Field Campaign**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Hawaii at Manoa,IPRC/SOEST,1680 East-West Road, POST Building 409B,Honolulu,HI,96822**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

observational campaign. We will examine how the cyclogenesis forecast may be significantly improved with a better description of the dynamic and thermodynamic precursor signals.

APPROACH

For understanding the synoptic aspect of cyclogenesis, a multi-nested WRF model (with 2 km resolution in the innermost mesh) will be used to simulate both idealized and real-case cyclogenesis events. Through the diagnosis of the model outputs, we intend to understand the common and different development characteristics associated with cyclogenesis in an environment with a near bottom vortex (EBV) and an environment with a mid-level vortex (EMV). The genesis time for each model run will be defined based on an objective way. A concept of the cyclogenesis efficiency (which is related to the initial environmental dynamic and thermodynamic conditions) will be introduced. A number of idealized experiments will be designed to illustrate the relative importance of initial column-integrated absolute vorticity, PBL parameters, surface fluxes, and vertically integrated relative humidity in determining the TC genesis efficiency.

For understanding the climatic aspect of cyclogenesis, various statistical tools such as the wavenumber-frequency analysis, lagged regression analysis, and composite analysis methods will be applied to understand the role of the MJO and ENSO in determining the intraseasonal and interannual variability of TC activity in the WNP.

For the data assimilation task, WRF 3DVar assimilation system will be employed. Because the TCS-08 campaign provides variety types of in-situ data at irregular spatial and temporal intervals, we intend to construct a high-resolution regular-grid reanalysis product that combines in-situ observations (such as ELDORA radar, Doppler wind lidar, dropsondes and driftsondes) with satellite remote sensing products.

WORK COMPLETED

The large-scale factors including the ENSO and MJO that affect multiple TC genesis in the WNP were investigated. A paper about occurrence of multiple TC events was published in 2011 in the Monthly Weather Review. A review paper entitled "Synoptic and climatic aspects of tropical cyclogenesis in western North Pacific" was accepted for publication as a chapter in a book named "*Cyclones: Formation, triggers and control" edited by K. Oouchi and H. Fudevasu.* The studies about TC track change under two types of El Ninos and dynamics of secondary eye wall were also accepted for publication in GRL and J. Atmos. Sci., respectively. A manuscript entitled "Tropical cyclone genesis efficiency: Mid-level versus bottom vortex" was submitted to J. Tropical Meteorology and is currently under revision.

Typhoon reanalysis during the period of TCS-08 campaign was completed. The TC reanalysis data are currently available at IPRC/UH website.

RESULTS

The statistical feature of occurrence of summer (June-September) multiple tropical cyclone (MTC) events in the western North Pacific was examined for the period of 1979-2006 (Gao and Li 2011). The

number of MTC events ranged from 1 to 8 per year, experiencing a marked interannual variation. The spatial distance between the TCs associated with MTC events is mostly less than 3000 km, which accounts for 73% of total samples. The longest active phase of a MTC event lasts for nine days, and about 80% of the MTC events last for five days or less.

A composite analysis of active and inactive MTC phases reveals that positive low-level (negative upper-level) vorticity anomalies and enhanced convection and mid-tropospheric relative humidity are the favorable large-scale conditions for MTC genesis. It is noted that the MTC events are closely associated with the Madden-Julian Oscillation (MJO) and the biweekly (10-20-day) oscillation (BWO). Figure 1 shows the composites of 25-70-day band-pass filtered OLR fields during the MTC inactive and active phase respectively. Note that during the MTC active phase, negative OLR anomalies associated with the MJO cover the entire SCS/WNP region from 110°E to the east of 170 °E and from 5°N to 25°N. The condition is completely reverse in the MTC inactive phase, in which positive intraseasonal OLR anomalies occupy the region. The difference is statistically significant, exceeding the 95% confidence level. This indicates that the MJO is in a wet (dry) phase with enhanced (suppressed) convective activity in WNP when an active (inactive) MTC phase occurs. This implies that the large-scale circulation anomaly associated with MJO favors the genesis of MTC events.

The BWO, on the other hand, shows a different spatial pattern (Fig. 1). It is found that during the MTC active phase a negative OLR anomaly appears west of 140 °E, while a positive OLR anomaly occurs to the east. The negative OLR anomaly to the west is stronger than the positive one to the east. Such a zonal dipole pattern is consistent with the fact that the BWO has a relatively short zonal wavelength compared to that of the MJO. An approximately opposite pattern of the OLR anomaly appears in the inactive MTC composite. The difference is most significant in a region from 125°E to 140°E. The result suggests that the strengthened BWO activity in that region favors the MTC generation in the WNP.

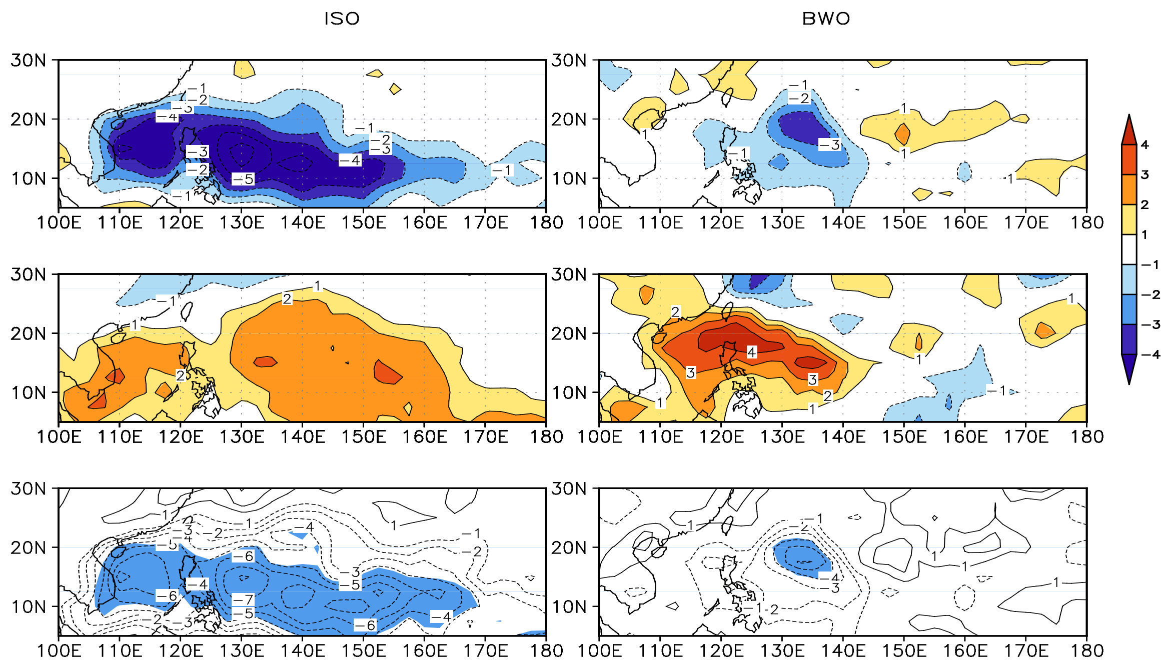

Figure 1. The 25-70-day (left) and 10-20-day (right) band-pass filtered OLR (unit: W/m²) fields composed based on MTC active (top panel) and inactive (middle panel) phases and their difference fields (bottom panel). The OLR anomalies with a value greater than 1 W/m² or less than -1 W/m² are shaded in top and middle panels. Shading in the bottom panel indicates that the difference between the active and inactive phase exceeds a 95% confidence level.

The possible effect of the large-scale control of the MJO and BWO may be revealed by counting the percentage of individual MTC events that appear during the active phases of the MJO and BWO respectively. Due to the spatial variability of cyclogenesis locations associated with the MTC events, the OLR values associated with the MJO and BWO at individual genesis locations on the genesis dates were calculated. Prior to that, a Lanczos filter is applied to the daily OLR field to extract the biweekly (10-20-day), intraseasonal (25-70-day) and lower frequency (> 90 days) components. The number of positive and negative OLR values was then counted at each of the genesis location and date for each of the following scenarios: the MJO mode only, the BWO mode only, sum of the MJO and BWO modes, and sum of the MJO, BWO and lower-frequency oscillation (LFO, >90 days) modes.

Table 1 shows the percentage of number of the negative OLR values during active MTC events for each of the scenarios above. It is found that about 77% of the TCs associated with the active MTC events occur when either BWO or MJO is in a wet phase. The combination of the BWO and MJO modes leads an increase of the occurrence percentage to 84%. This implies that the predictability of the MTC events might increase when one considers both the MJO and BWO impacts. The percentage of occurrence of the MTC events increases further to 98% when the combined BWO, MJO and LFO forcing effects are included.

Table 1. The percentage of occurrence of the MTC events in the genesis locations where the BWO, MJO and/or LFO are in a wet phase

Mode	**Percentage of occurrence of negative OLR values**
BWO (10-20-day)	77.30
MJO (25-70-day)	76.69
BWO + MJO	84.05
BWO + MJO + LFO	97.85

The observational analysis result above indicates that the occurrence of the MTC events is greatly regulated by the combined large-scale impacts of the BWO, MJO and the lower-frequency oscillation. On the interannual timescale, the MTC frequency is closely related to the seasonal mean anomalies of 850-hPa vorticity, OLR and 500-hPa humidity fields. The MJO and BWO activity is greatly strengthened (weakened) in the WNP region during the MTC active (inactive) years.

Impacts of two types of El Niños, the eastern Pacific El Niño (EP-EN) and the central Pacific El Niño (CP-EN), on tropical cyclone (TC) tracks over the western North Pacific (WNP) were examined based on observational data (Hong et al. 2011). Whereas TC tracks between CP-EN and EP-EN show a small difference in boreal summer (JJA), they do exhibit a great difference in boreal autumn (SON), that is, TCs recurve northward at a further westward location near the coastline of East Asia during CP-EN. As a consequence, more TCs make landfall to Taiwan and South China during CP-EN. A further observational analysis indicates that the westward shift of the subtropical high and associated steering flow during CP-EN is a key factor that causes the difference in the TC tracks in autumn. Numerical experiments further suggest that the difference of local SST in the WNP between CP-EN and EP-EN accounts for the distinctive differences in the local Hadley circulation, the subtropical high and the TC steering flow.

IMPACT/APPLICATIONS

The investigation of dependence of TC genesis efficiency on initial vortex structure and large-scale factors that control TC genesis and the construction of the typhoon reanalysis product may improve our current understanding of cyclogenesis dynamics and promote a more skillful prediction of TC genesis and intensity change.

TRANSITIONS

Results from this study may lead to improvement of TC prediciton in the NOGAPS and COAMPS models. The TC dynamic initializ scheme used in the typhoon reanalysis effort may be transitioned into a 6.4 project.

RELATED PROJECTS

This project is complimentary to the ONR funding entitled "Initialization of tropical cyclone structure for operational application" in which we applied TC dynamic initialization strategy to the Observation System Simulation Experiment (OSSE) in an idealized setting using the WRF model and real-case TC forecast during 2009-2010 using NRL COAMPS-TC model. Knowledge gained from this project will help improve the current operational model TC initialization.

PUBLICATIONS

The following are papers published in 2011 that are fully or partially supported by this ONR grant:

Li, T., 2011: Synoptic and climatic aspects of tropical cyclogenesis in western North Pacific. in *Cyclones: Formation, triggers and control, edited by K. Oouchi and H. Fudevasu, Noval Science Publishers*, in press.

Hong, C.-C. Y.-H. Li, T. Li , and M.-Y. Lee, 2011: Impacts of Central Pacific and Eastern Pacific El Niños on tropical cyclone tracks over the western North Pacific. *Geophysical Research Letters*, in press.

Gao, J.-Y., and T. Li, 2011: Factors controlling multiple tropical cyclone events in the western North Pacific. *Mon.Wea.Rev*., in press.

Zhou, X., B. Wang, X. Ge, and T. Li, 2011: Impact of secondary eyewall heating on tropical cyclone intensity change during eyewall replacement. *J.Atmos.Sci*., in press.

Wang, L., T. Li, and T. Zhou, 2011: Intraseasonal SST Variability and Air-Sea Interaction over Kuroshio Extension Region during Boreal Summer. *J. Climate*, in press.

Wu, B., T. Zhou, and T. Li, 2011: Two distinct modes of tropical Indian Ocean precipitation in boreal winter and their impacts on equatorial western Pacific. *J. Climate*, in press.

Chung, P., C. Sui, and T. Li (2011), Interannual relationships between the tropical sea surface temperature and summertime subtropical anticyclone over the western North Pacific, J. Geophys. Res., 116, D13111, doi:10.1029/2010JD015554.

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Hsu, P.-C., T. Li, and B. Wang, 2011: Trends in Global Monsoon Area and Precipitation over the Past 30 Years. *Geophys. Res. Lett*., 38, L08701, doi:10.1029/2011GL046893

Rong, X., R. Zhang, T. Li, and J. Su, 2011: Upscale feedback of high-frequency winds to ENSO. *Q. J. R. Meteorol. Soc*., 137, 894-907.

Xiang, B., W. Yu, T. Li, and B. Wang, 2011: The critical role of the boreal summer mean state in the development of the IOD. *Geophys. Res. Lett*., in press.

Lin, A.-L., T. Li, X. Fu, J.-J. Luo, and Y. Masumoto, 2011: Effects of air-sea coupling on the boreal summer intraseasonal oscillations over the tropical Indian Ocean, *Clim. Dyn*., in press.

Hsu, P.C., T. Li, and C.-H. Tsou, 2011: Interactions between boreal summer intraseasonal oscillations and synoptic-scale disturbances over the western North Pacific. Part I: Energetics diagnosis. *J. Climate*, **24**, 927-941.

Hsu, P.C., and T. Li, 2011: Interactions between boreal summer intraseasonal oscillations and synoptic-scale disturbances over the western North Pacific. Part II: Apparent heat and moisture sources and eddy momentum transport. *J. Climate*, **24**, 942-961.

Manuscript in revision

Ge, X., T. Li, and M. S. Peng, 2011: Tropical cyclone genesis efficiency: Mid-level versus bottom precursor vortex. *J. Tropical Meteorology*, in revision.